

Remote Seabed Sediment Classification and Sediment Property Estimation Using High Resolution Reflection Profiles

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LONG TERM GOALS

The long term research objective is to develop a cost effective technique for mapping the top 20 meters of sediment properties using acoustic remote sensing. In previous years, a chirp sonar was developed to provide quantitative, wideband reflection measurements of the seabed with a vertical resolution of 10 cm. Neural network and fuzzy logic techniques have been used to automatically detect subsurface layer interfaces and to find the boundaries between sediment layers. Signal processing techniques were developed to estimate vertical profiles of impedance, attenuation and volume scattering coefficients. The procedures for remotely estimating sediment properties are being verified using core data and in situ measurements. New signal processing techniques have been developed that allow several sources transmitting simultaneously in different bands to build a wideband FM pulse in the far field. That wideband data is being used to improve the accuracy of the sediment classification procedures.

OBJECTIVES

- 1) Conduct chirp sonar surveys to provide imagery that will be used in High Frequency DRI site selection and to collect calibrated wideband reflection data during the DRI experiments.
- 2) Expand the bandwidth of the chirp sonar from 1-15kHz to 1-45 kHz. A 40 kHz bandwidth will provide a vertical resolution in subsurface images approximately equal to 1 cm.
- 3) Compare remote chirp measurements of sediment properties with properties measured by other investigators conducting acoustic experiments and coring surveys.
- 4) Use the chirp sonar to measure a) the frequency dependence of the surficial reflection coefficient and subsurface reflectors b) the frequency dependence of compressional wave attenuation and c) phase dispersion and compare those measurements with the outputs of propagation models developed by other investigators.

APPROACH

The technical approach for the SAX99 survey was to collect normal incidence reflection data with a towed chirp sonar over the range of 1 to 45 kHz to provide images of the top meter of sediments for use by DRI scientists searching for a site for high frequency bottom-interacting acoustic experiments and to provide a data set for estimating sediment properties. The multiband technology allows the

collection of normal incidence reflection data over a band of 1 to 45 kHz while the towed vehicle emulates a point acoustic source. The point source is emulated using 3 piston sources that operate over different but overlapping frequency bands. Each single piston source has a wide beamwidth (greater than 40 degrees) over its band of operation. Multiple transducers can be driven simultaneously with chirp pulses with different bands to generate the wideband chirp pulse in the water that appears (in the far field) to emanate from a point acoustic source. Multiple rectangular receiving arrays of various sizes are used to control receiving beamwidth and scattering by spatial filtering. The bandwidth of the sonar provides subsurface imagery approaching 1 cm in vertical resolution. The enhanced bandwidth also improves the accuracy of attenuation and phase measurements needed for impedance inversion and dispersion measurements.

Dr. Schock supervises the research program including graduate and undergraduate students and at sea experiments. Earnest Arrizi, a graduate student, who attended at sea experiments, and processed the data sets, is writing his thesis on the frequency dependence of the reflection coefficient. Jim Wulf is the lead engineer on the project for expanding the sonar bandwidth.

WORK COMPLETED

During July and October 1999, chirp sonar surveys were conducted off Panama City and Fort Walton Beach, Florida to collect 1) high resolution images of the top 5 meters of the sediments and 2) quantitative FM reflection data. The acoustic subsurface images of the seabed collected during the first cruise were used by the chief scientist to select a site consisting of relatively homogeneous sandy sediments for the October 1999 High Frequency Acoustics DRI experiment off Fort Walton Beach. During the July 1999 survey, chirp data was collected over the band of 1 – 15 kHz. The October 1999 survey collected chirp data over the band of 1-45 kHz. Imagery had approximately 1cm of vertical resolution. Extensive calibration and testing procedures were conducted to ensure the sonar had an absolute calibration over the entire operating band.

RESULTS

The most significant result for the past year was that the accuracy of remotely estimating the insitu attenuation coefficient measurement was verified at the APL tower site off Fort Walton Beach by comparing chirp data predictions and insitu measurements of attenuation collected by two insitu measurement systems deployed by other investigators. Investigators from APL, Washington State, measured an insitu attenuation coefficient of 0.30 dB/m/kHz over 10 to 300 kHz in surficial sediments between the subsurface depths of 5 and 45cm and NRL's ISSAMS measured the insitu attenuation coefficient of 0.32 dB/m/kHz using 40 kHz transducers at depths of 10 to 30 cm in the surficial sediments. Both of these coefficients were calculated assuming that attenuation (dB/m) is proportional to frequency. The attenuation coefficient of the top meter of sediment at the APL tower site was estimated from chirp sonar data using the energy from a reflector about 4 meters below the sediment-water interface corresponding to the boundary between sand and clay shown in vibrocoring records. The slope of the attenuation versus frequency plot over the range of 2 to 12 kHz was 0.35 dB/m/kHz, the remotely predicted attenuation coefficient. The attenuation of the top meter of sediment was measured to be 0.31 dB/m/kHz using the echoes from a reflector 1 meter below the seafloor. These chirp measurements make no assumption about the attenuation mechanism or the attenuation function intercept. The reported attenuation coefficient is the slope of the attenuation function fitted to the band of 2 to 12 kHz using least squares. The plot of attenuation versus frequency shown in figure 2 shows

that the relationship between attenuation (dB/m) and frequency (kHz) is approximately linear over the band of 2 to 12 kHz.

This method for remotely measuring compressional wave attenuation as a function of frequency is more accurate than other remote methods for remotely predicting attenuation from normal incidence data because it does not require gating reflections in the time domain and the resulting truncation errors. The echoes used in the attenuation measurement calculation are located within the dataset using a fuzzy logic technique for automatically locating sediment layer interfaces.

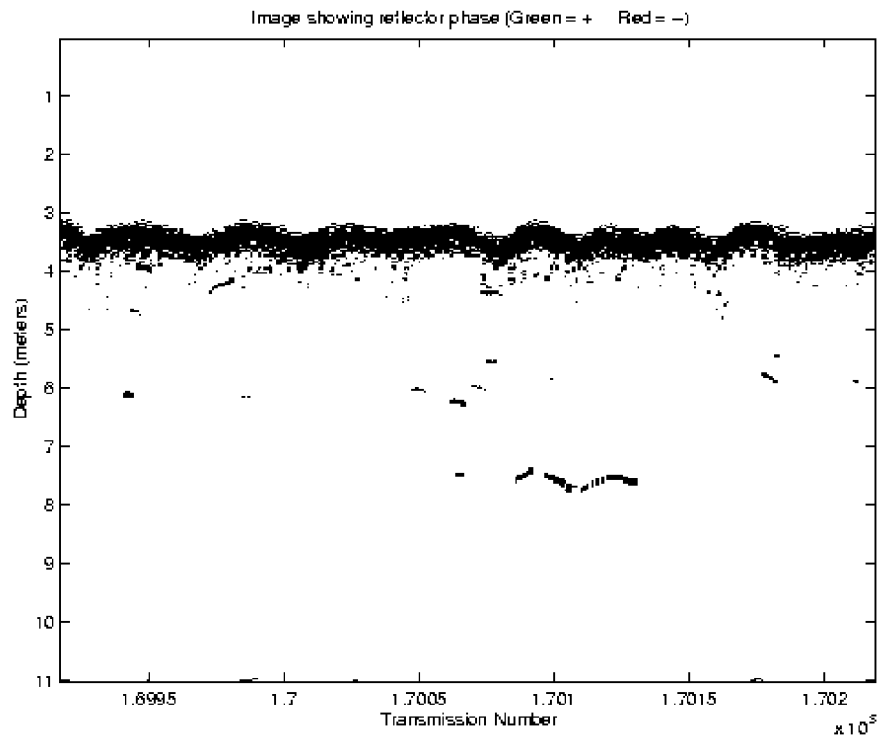


Figure 1. Subbottom profile at APL tower site showing a detected interface located 4 meters below the seafloor. The reflection off the interface was used to calculate the attenuation coefficient of the top 4 meters of sediment.

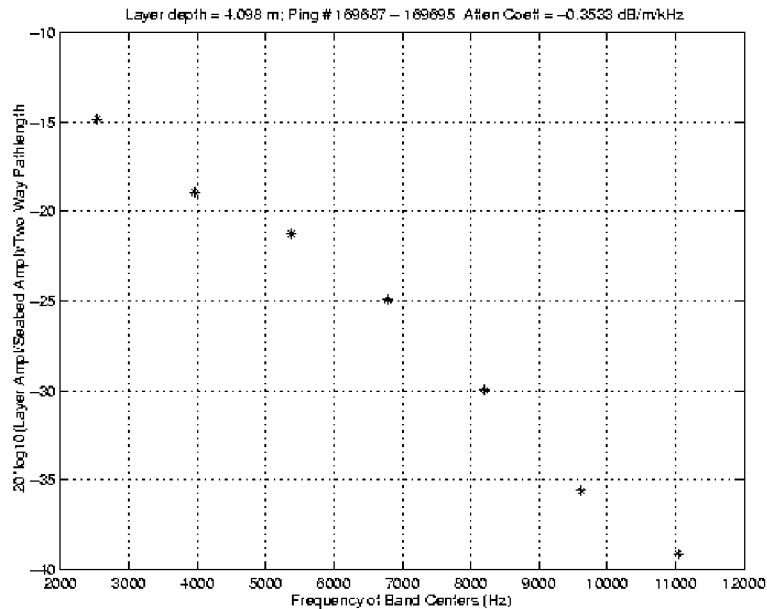


Figure 2. Plot of attenuation versus frequency for the top 4 meters of sediments at the APL tower site. This plot was generated using the detected echo shown in Figure 1. The slope of the attenuation function is approximately linear and is equal to 0.35 dB/m/kHz, the attenuation coefficient of the top 4 meters of sediment at the APL tower site.

Another result was the high resolution images generated by the enhanced bandwidth of the chirp sonar. Sonar images approached 1 cm in resolution using the band of 1 to 45 kHz. Signal processing and calibration procedures were verified that allowed simultaneously driving multiple FM sources in several bands effectively creating a point source with a flat spectrum in the far field which is very useful for measuring the frequency dependence of the reflection coefficient without errors due to vehicle motion.

IMPACT/APPLICATIONS

Instrumentation and sediment classification procedures have been developed to predict the acoustic and physical properties of the seabed using normal incidence reflection data collected by FM subbottom profilers. This development provides a cost effective method of surveying the top 20 meters of the seabed and obtaining vertical profiles of attenuation, acoustic impedance, volume scattering. From these acoustic property profiles, vertical profiles of physical properties such as bulk density, grain size, and porosity can be estimated. The sonar can also provide calibrated measurements of the seabed reflection coefficient and buried target strengths over the band of 1-45 kHz

TRANSITIONS

The chirp sonar, which evolved out of this program, was transitioned to industry in the early 1990s and has become the standard ocean industry instrument for conducting high resolution ocean surveys. Edgetech, Inc. has started manufacturing multi-band chirp sonars. The first two multi-band chirp sonars were delivered to NAVFAC and Woods Hole Oceanographic Institution.

RELATED PROJECTS

“Remote Sediment Property Estimation From Chirp Data Collected During ASIAEX,” ONR G&G Grant. The chirp sonar is being used to remotely predict sediment properties in the East and South China Seas using the same techniques as described in this report.

PUBLICATIONS

1. " The Development of Chirp Sonar Technology and Its Applications, " S. G. Schock and L. R. LeBlanc, AGU Abstract, Dec., 2000. (Submitted)
2. “Overview of SAX99: Environmental Considerations,” Richardson et al., IEEE J. of Oceanic Engineering (Accepted, under revision)